Higgs production in association with a single top quark at the LHC

Federico Demartin
UCLouvain (CP3)

FD, F. Maltoni, K. Mawatari, M. Zaro,
[arXiv:1504.00611]

01.06.2015

Experimental searches of tH

- *ATLAS*: [arXiv:1409.3122] ($H \to \gamma\gamma$, only as part of $t\bar{t}H$ analysis)
- *CMS*: CMS-PAS-HIG-14-001, -14-015, -14-026 ($H \to \gamma\gamma$, $b\bar{b}$, WW^* optimized for $y_t = -y_{t,SM}$)

At the moment: limits on tH cross sections $>$ SM

Previous pheno studies

- *Maltoni*, *Paul*, *Stelzer*, *Willenbrock* [arXiv:hep-ph/0106293] (LO, sig+bkg)
- *Biswas*, *Gabrielli*, *Mele* [arXiv:1211.0499] (LO, $H \to \gamma\gamma$ sig+bkg)
- *Farina*, *Grojean*, *Maltoni*, *Salvioni*, *Thamm* [arXiv:1211.3736] (NLO xsect 5F, LO distr, $H \to b\bar{b}$ sig+bkg, $\pm y_t$)
- *Ellis*, *Hwang*, *Sakurai*, *Takeuchi* [arXiv:1312.5736] (LO, sign/phase of y_t)
- *Chang*, *Cheung*, *Lee*, *Lu* [arXiv:1403.2053] (LO distr, $H \to b\bar{b}, \gamma\gamma, 4\ell, \tau^+\tau^-$ sig+bkg, detector simulation, $\pm y_t$)

Aims of our work

(1) Reliable tH cross section at NLO-QCD with uncertainties

Compare & combine flavour schemes: 4F vs 5F

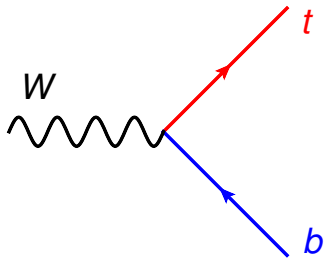
Scale(s), PDFs, $\alpha_s(m_Z)$, m_b

(2) Study distributions at NLO-QCD + parton shower

MG5_aMC@NLO + Pythia8 with 4F and 5F

(3) Possibility to study sign/phase of y_t

Single-top (+ H) production: scale hierarchy



$\Lambda_{\rm QCD}$ $\xleftrightarrow{\sim \times 20}$ m_b $\xleftrightarrow{\sim \times 25-35}$ μ $\longleftrightarrow$ $(m_H)\,, m_t\,, \sqrt{\hat{s}}$

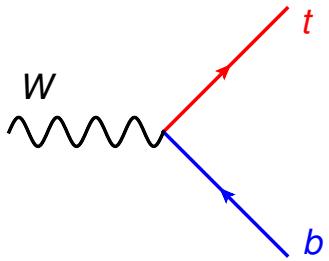
Choose unphysical regulator(s) here

Maltoni, *Ridolfi*, *Ubiali* [arXiv:1203.6393]

$\log(m_{b,t}/\mu)$ globally under control

(and $\log(\Lambda_{QCD}/\mu)$ resummed to all orders)

Single-top (+ H) production: scale hierarchy



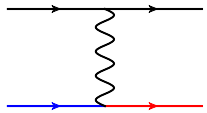
$\Lambda_{\rm QCD}$ $\xleftrightarrow{\sim\ \times 20}$ m_b $\xleftrightarrow{\sim\ \times 25-35}$ μ $\longleftrightarrow$ $(m_H)\,, m_t\,, \sqrt{\hat{s}}$

Choose unphysical regulator(s) here

Maltoni, *Ridolfi*, *Ubiali* [arXiv:1203.6393]

$\log(m_{b,t}/\mu)$ globally under control (and $\log(\Lambda_{QCD}/\mu)$ resummed to all orders)

Now choose FS: 5F scheme (b's appear in the initial state)



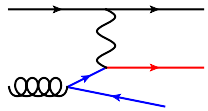
Neglect

$\alpha_s^n(\mu)\,(m_b/\mu)^m \quad (m_b = 0)$ distr: $p_T(b)$ (at LO)

Resum to all orders

$\alpha_s^n(\mu)\,\log^n(m_b/\mu)$

. . . or 4F scheme (generate b's in the hard scattering)



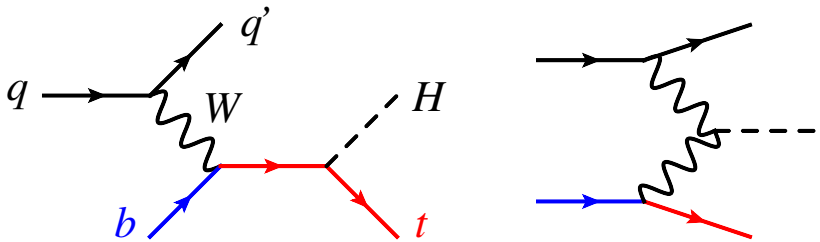
Compute at fixed order

$\alpha_s^n(\mu)\,(m_b/\mu)^m$ $\alpha_s^n(\mu)\,\log^n(m_b/\mu)$ distr: $p_T(b)$

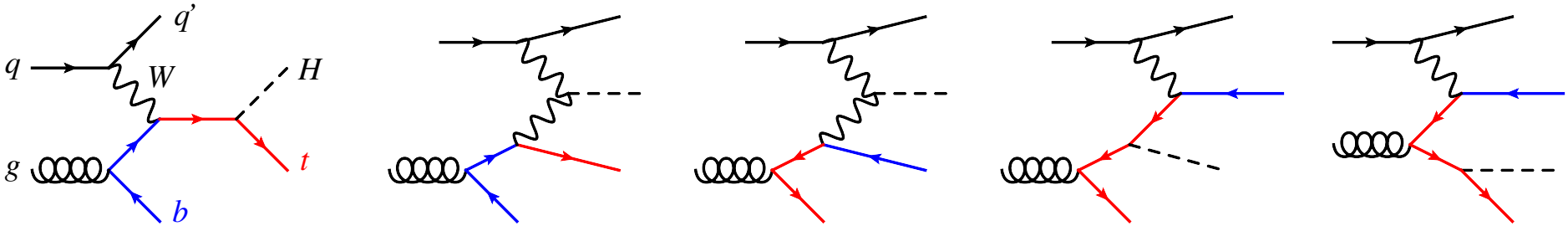
Go to NLO to reduce differences (i.e. flavour-scheme dependence)

Single top plus Higgs production (tH) at the LHC

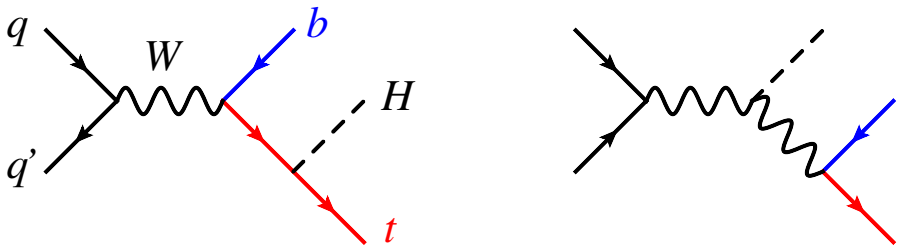
t-channel 5F



t-channel 4F

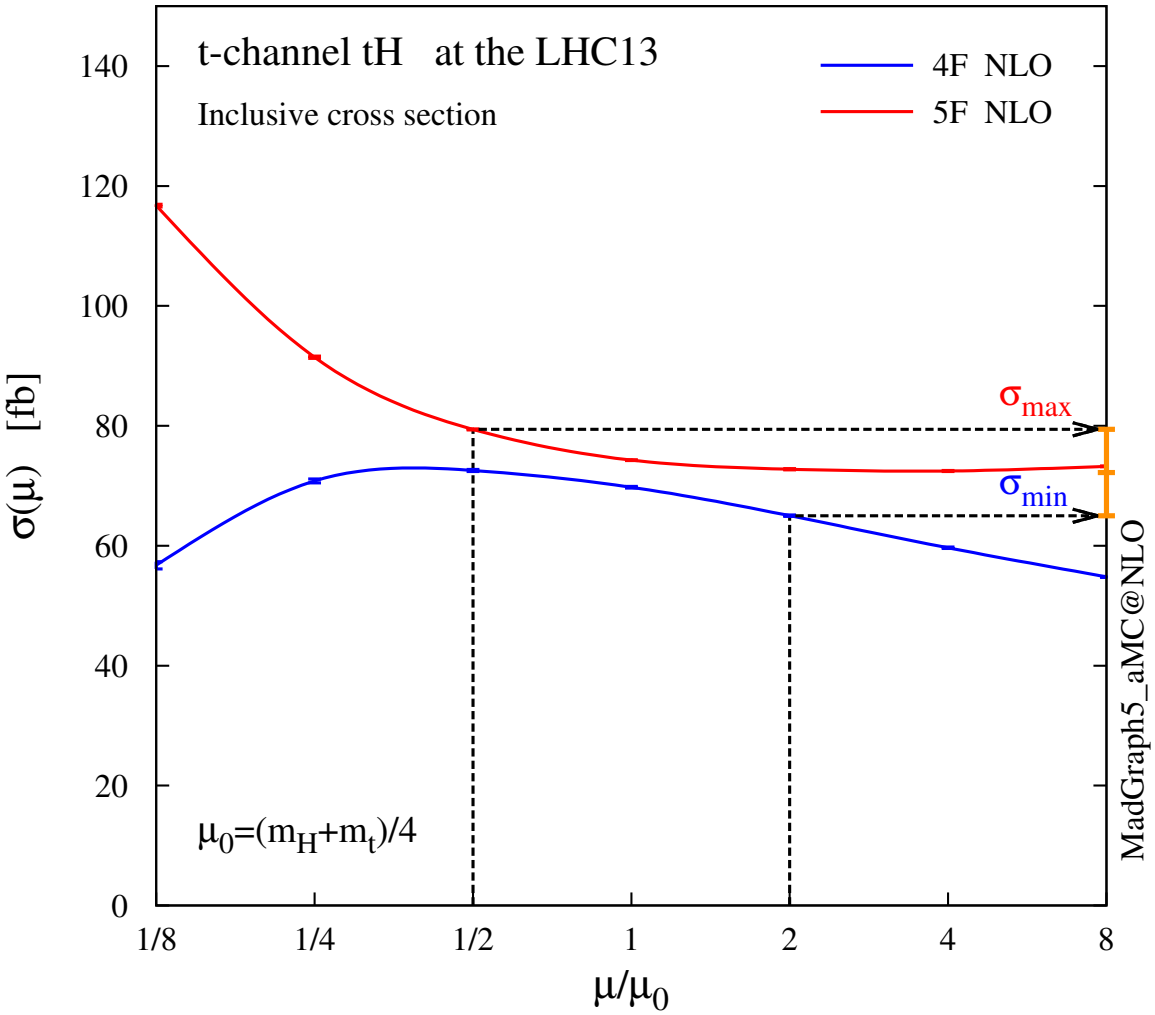


s-channel 4F (no FS ambiguity here)



tH NLO cross section: FS and μ dependence

Reverse approach: choose μ_0 minimizing FS dependence at NLO



$\mu_R = \mu_F \equiv \mu$

FS and μ are correlated

(1) Vary μ/μ_0 by 2 and take the envelope

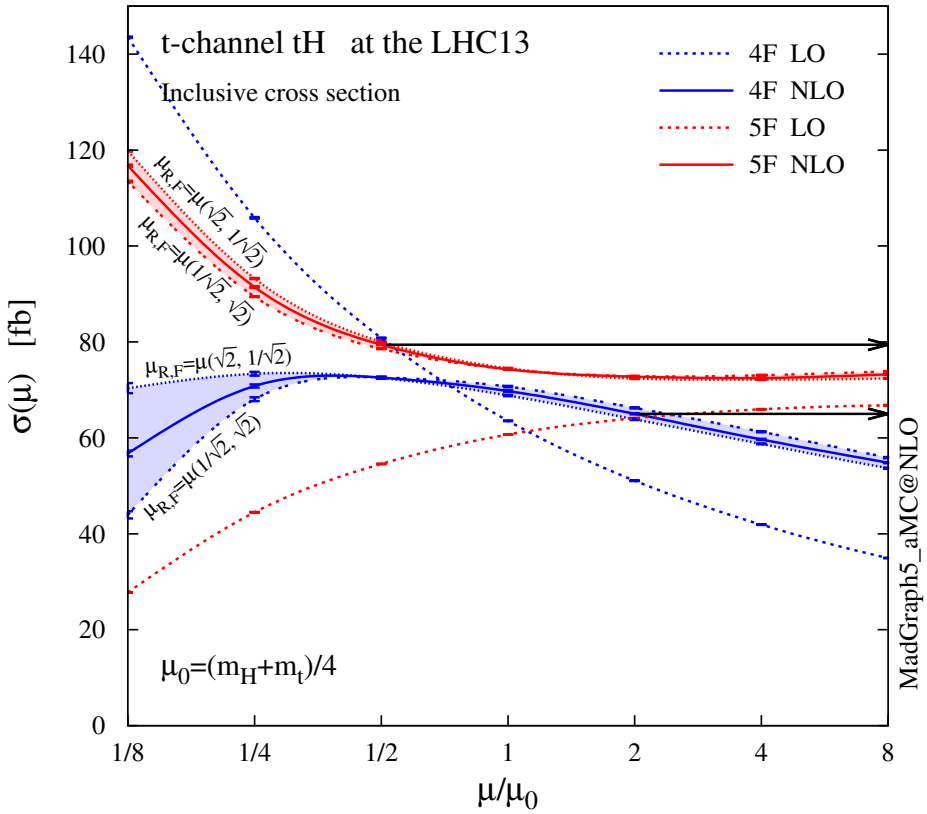
(2) Define

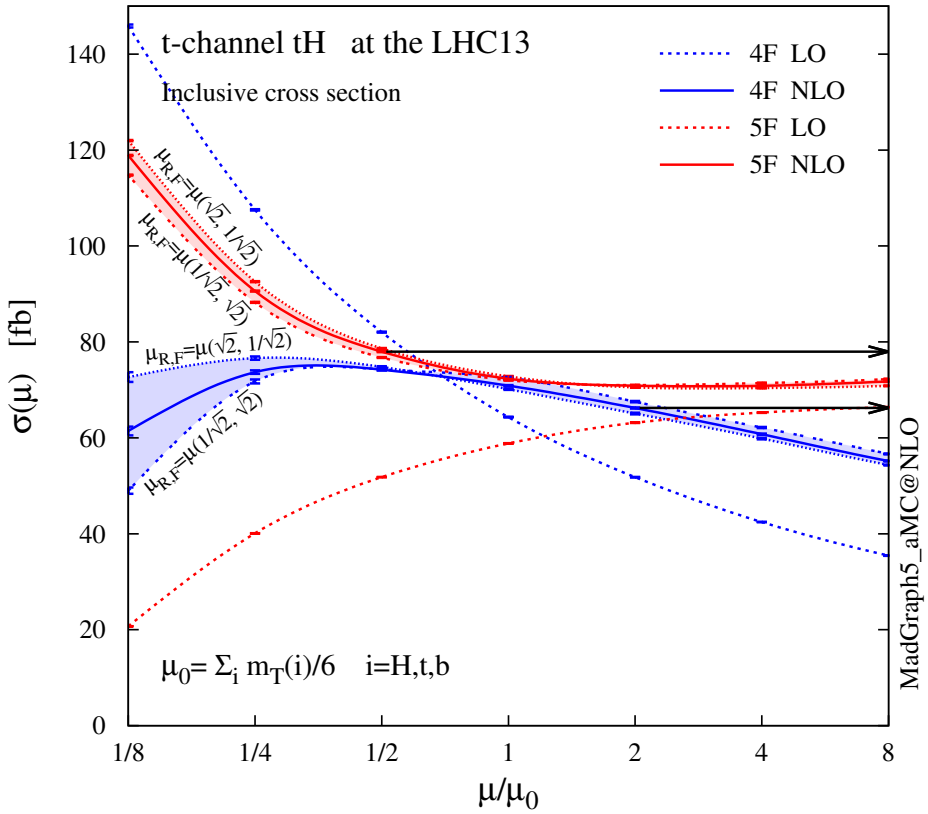
$$\sigma_0 \equiv (\sigma_{\max} + \sigma_{\min})/2$$

$$\delta_{\mu+\mathrm{FS}} \equiv (\sigma_{\max} - \sigma_{\min})/2$$

$$\boldsymbol{\sigma_{\mathrm{NLO}}^{\mathrm{comb.}} = \sigma_0 \pm \delta_{\mu+\mathrm{FS}}}$$

tH NLO cross section: flavour-scheme (FS) and μ dependence

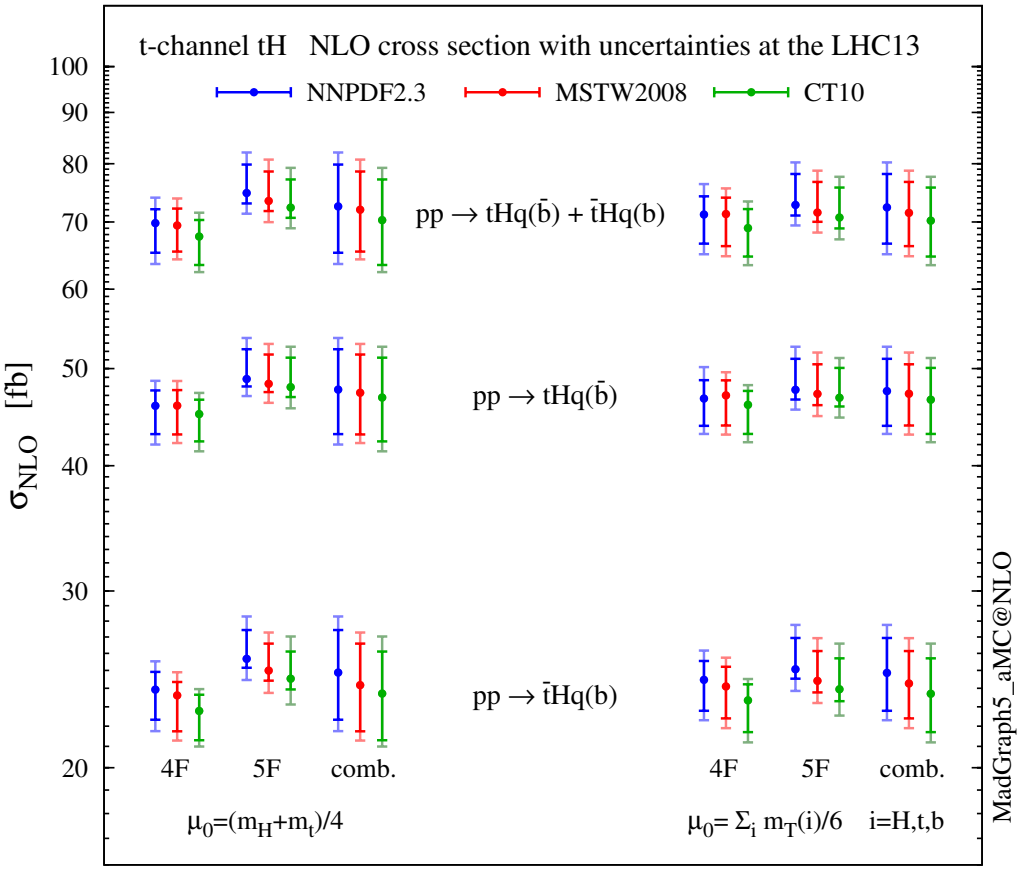




$\mu_R \neq \mu_F$ doesn't change the game

Definition of $\sigma_{\text{NLO}}^{\text{comb.}}$ stable when using dynamic scale

tH NLO cross section: total theoretical uncertainty



PDF global fits:
NNPDF2.3, MST2008, CT10

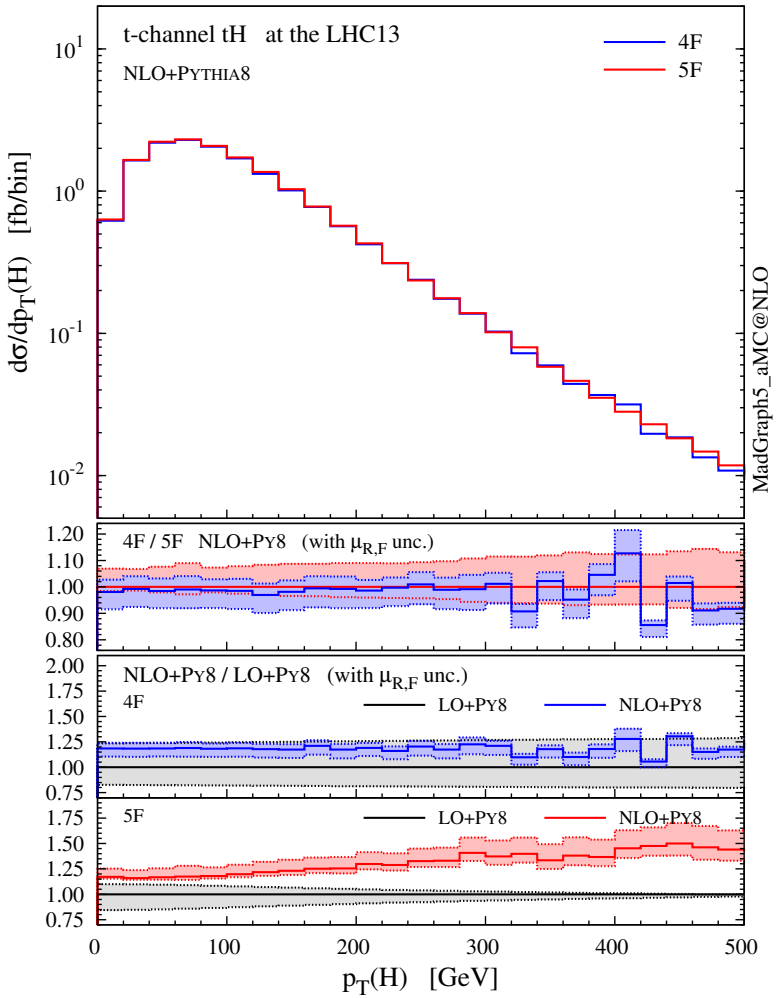
$$\alpha_s^{(5\mathrm{F})}(m_Z) = 0.1190 \pm 0.0012$$
$$\Leftrightarrow \alpha_s(m_b) = 0.2189 \pm 0.0042$$

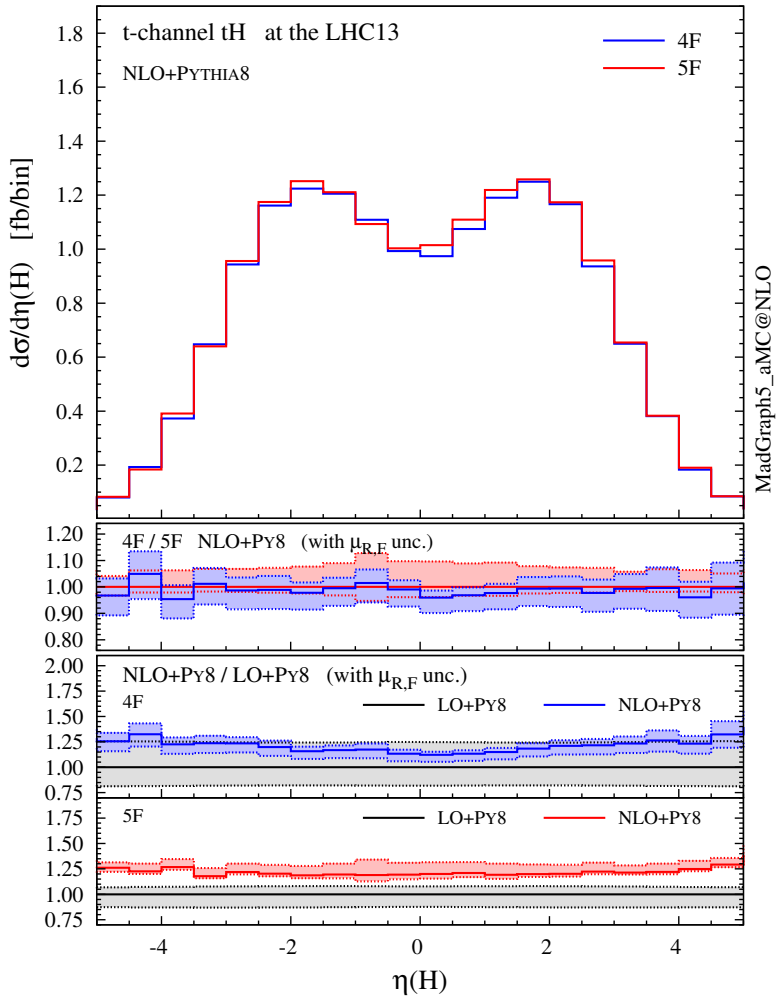
$$m_b^{(\mathrm{o.s.})} = 4.75 \pm 0.25 \text{ GeV}$$

$$\delta^{\pm}_{\mathrm{PDF}+\alpha_s+m_b} = \sqrt{(\delta^{\pm}_{\mathrm{PDF}})^2 + (\delta^{\pm}_{\alpha_s})^2 + (\delta^{\pm}_{m_b})^2}$$

$$\boldsymbol{\delta^{\pm}_{\mathrm{tot}} = \delta^{\pm}_{\mu(+\mathrm{FS})} + \delta^{\pm}_{\mathrm{PDF}+\alpha_s+m_b}}$$

tH NLO+PS distributions: Higgs (no decay)



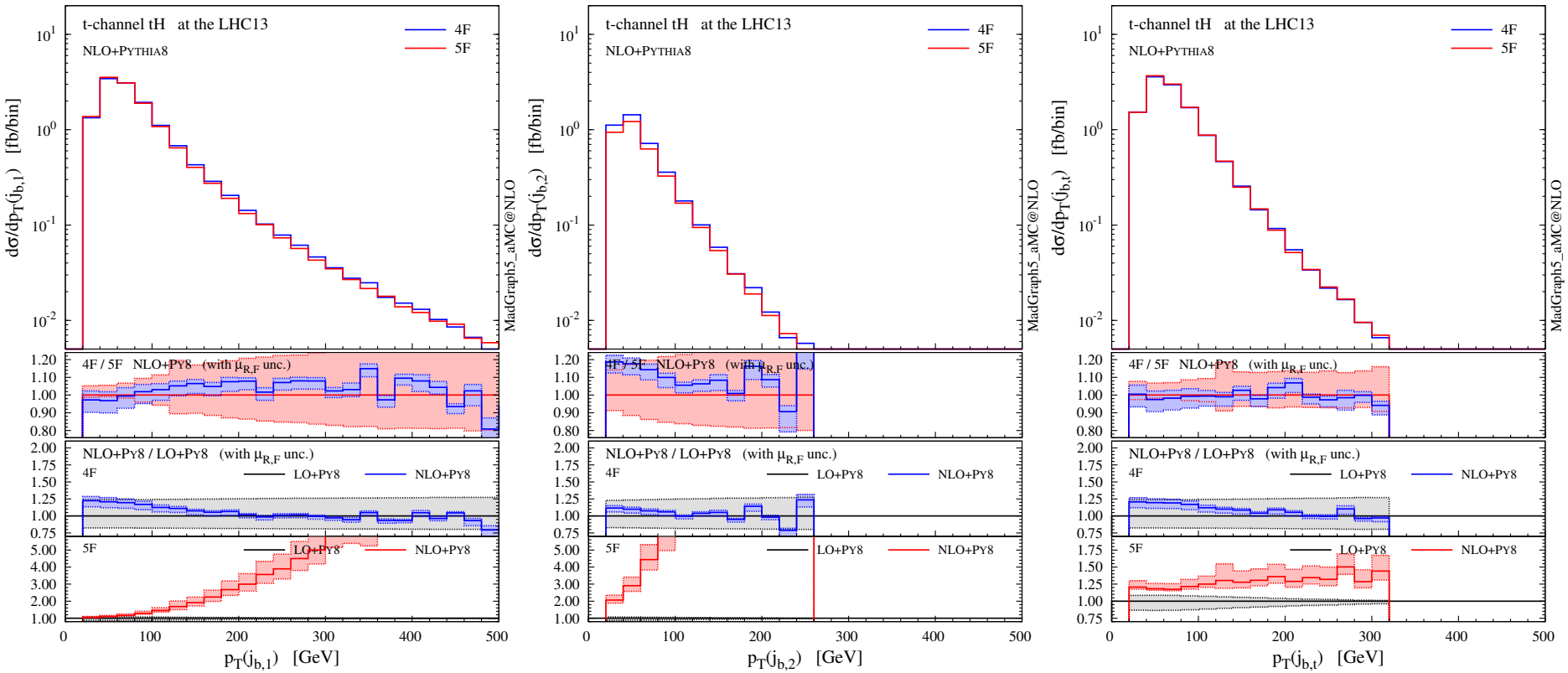


Very good agreement between 4F and 5F shapes at NLO (same for the top quark)

LO 5F provides a poor description

tH NLO+PS distributions: b-tagged jets

anti-k_T $p_T > 30$ GeV $R = 0.4$ $|\eta| < 2.5$ no H decay, $t \to b\ell\nu_\ell$

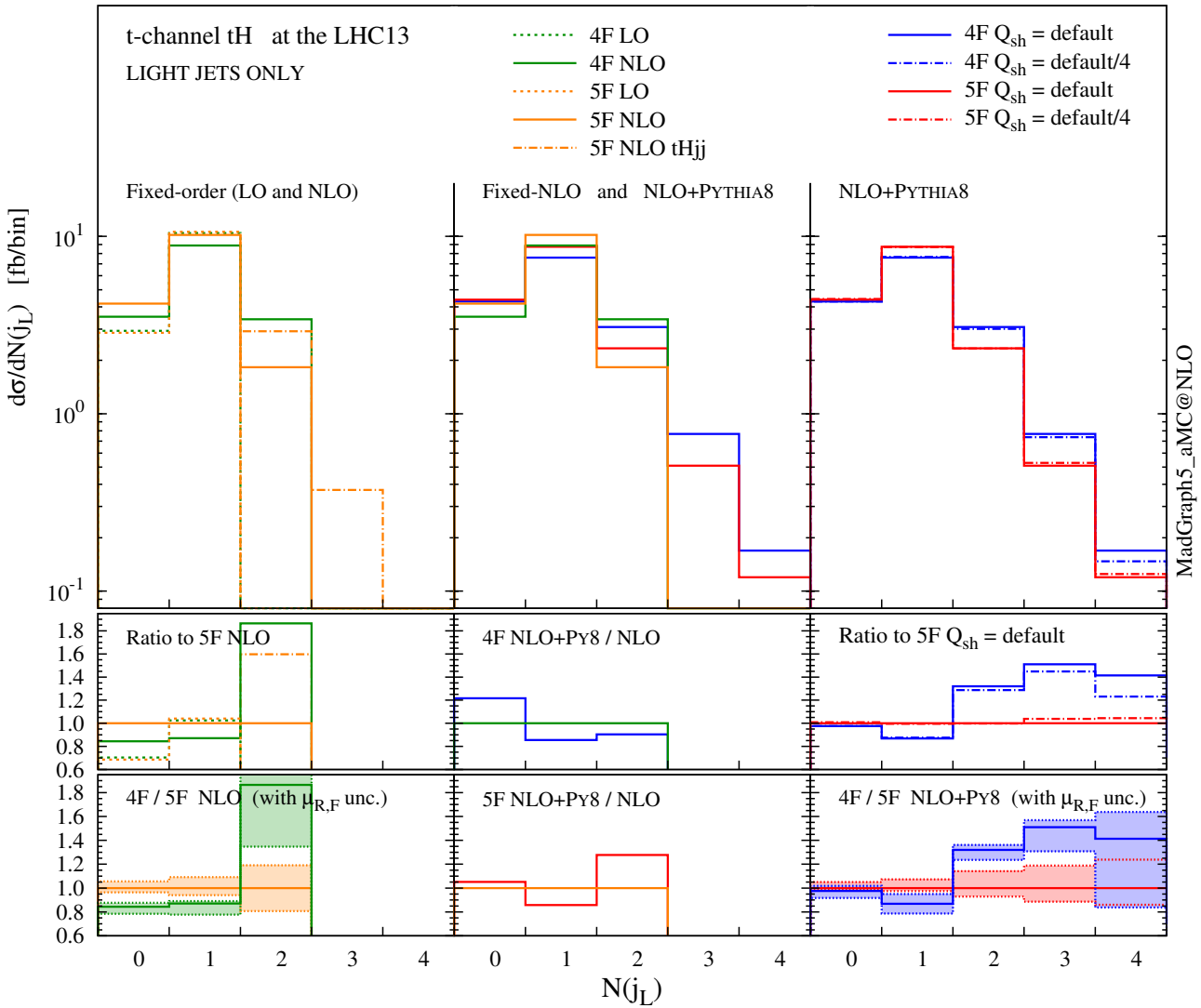


Still good agreement at NLO

1st b-jet comes from top decay in the low-p_T region,
from hard $g \to b\bar{b}$ splitting in the high-p_T tail

tH NLO+PS distributions: light jets

anti-k_T $p_T > 30$ GeV $R = 0.4$ $|\eta| < 4.5$ no H decay, $t \to b\ell\nu_\ell$

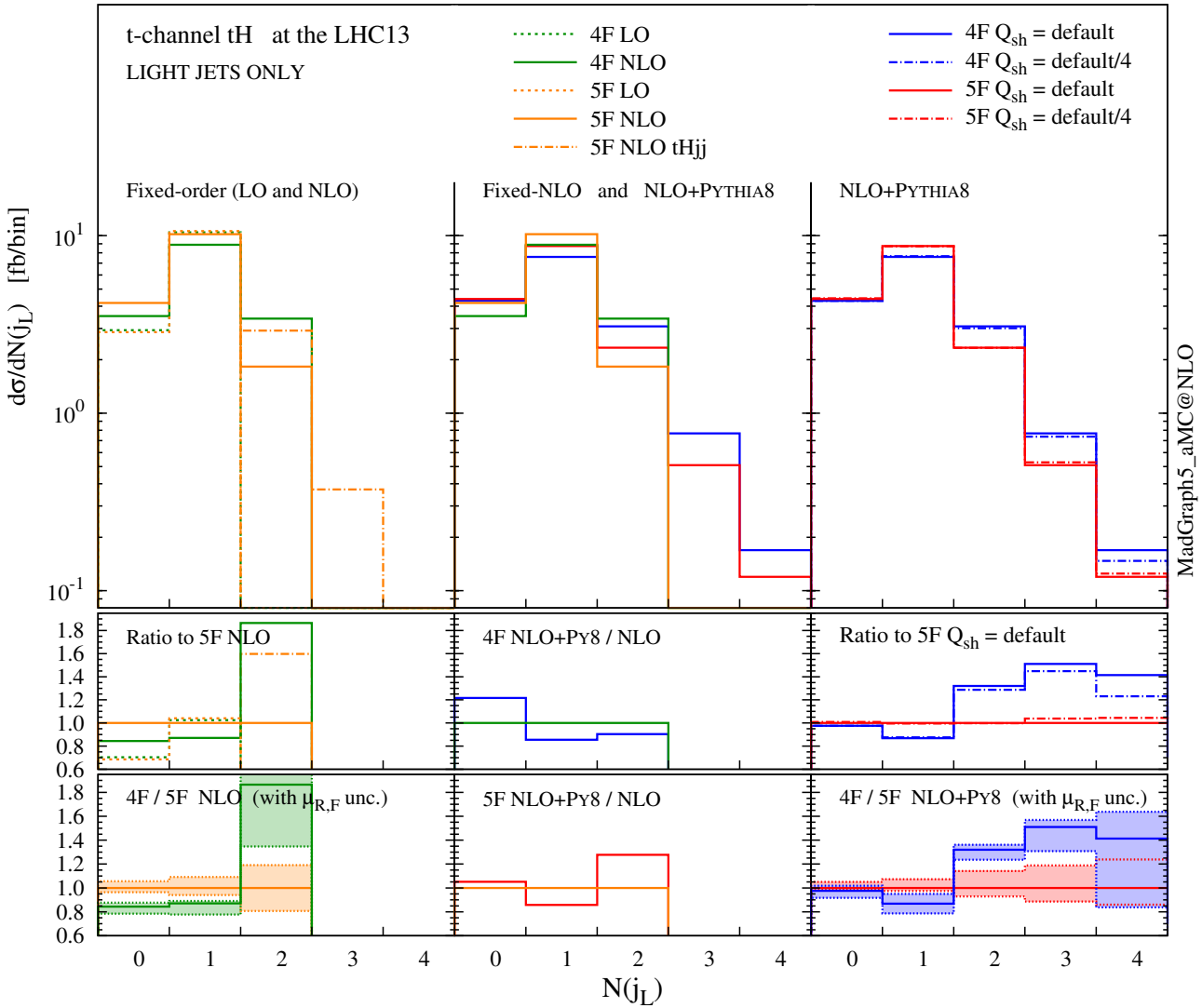


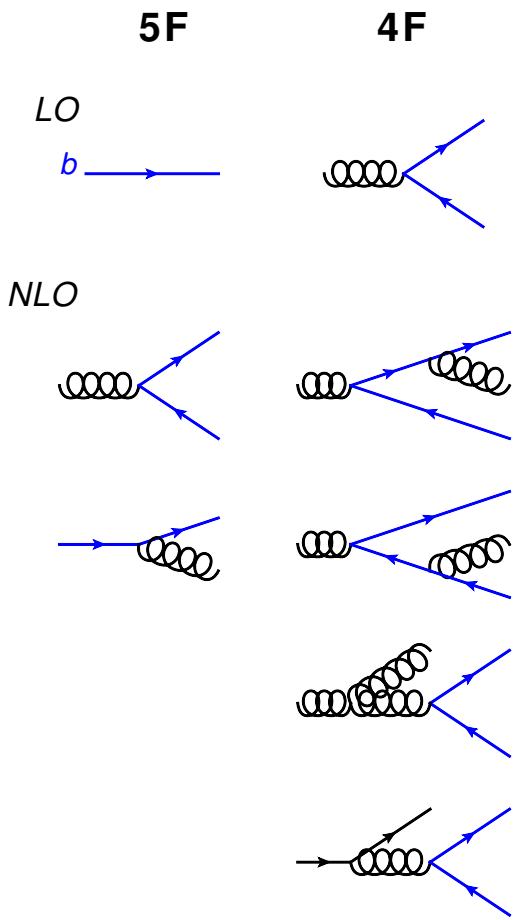
4F/5F discrepancy starts at fixed-NLO

It's reduced after the shower

It's related to the description of the $g \to b\bar{b}$ splitting

tH NLO+PS distributions: light jets





Conclusions (1)

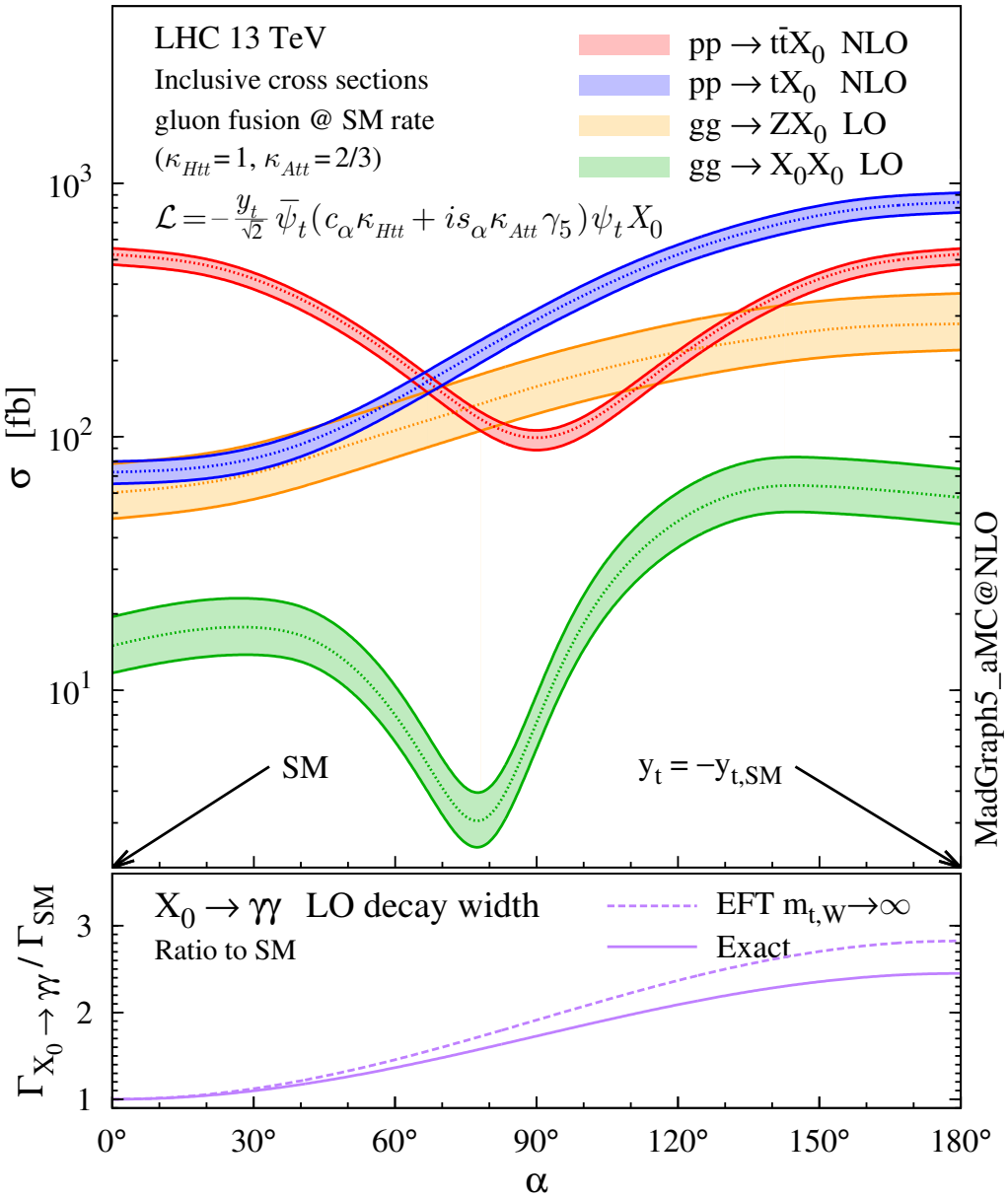
1. Both 4F and 5F are good to describe the NLO cross section
   $\Rightarrow$ combine

2. Carefully assessed the major sources of uncertainty in the cross section
   $\sigma_{\mathrm{NLO}}^{t-\mathrm{channel}} \simeq 72$ fb $\pm 8\%$ (μ+FS) $\pm 3\%$ (PDF+$\alpha_s + m_b$)
   (larger PDF uncertainty if considering systematics in the fitting procedure)

3. Both 4F and 5F are good to describe Higgs and top distributions
   (at NLO!)

4. 4F at NLO describes correctly many more distributions

Higgs characterisation: inclusive observables



α = CP-mixing angle

$\kappa_{Htt} = 1\,, \quad \kappa_{Att} = 2/3$

$\Rightarrow$ Gluon fusion @ SM rate $\forall\alpha$

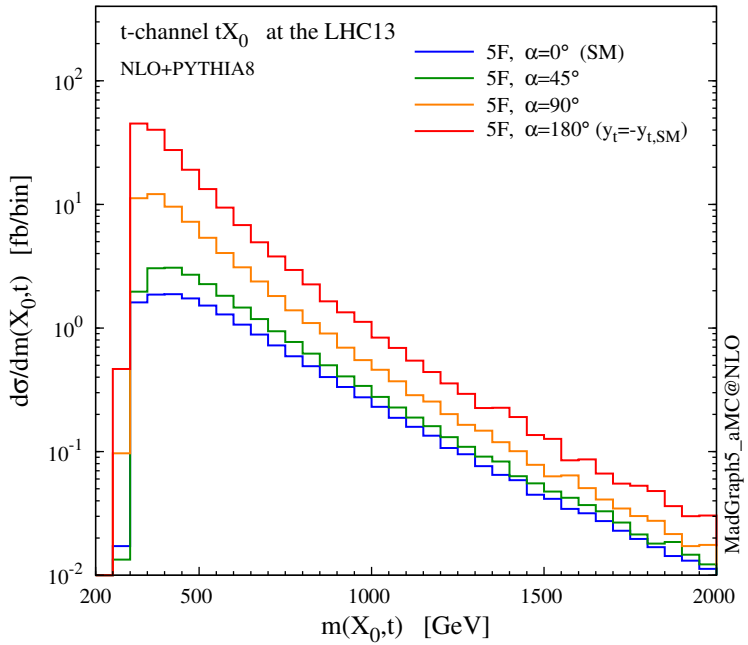
$t\bar{t}H$ helps to constrain α

tH and other rare processes further lift 2 degeneracies:

$y_t \leftrightarrow -y_t$

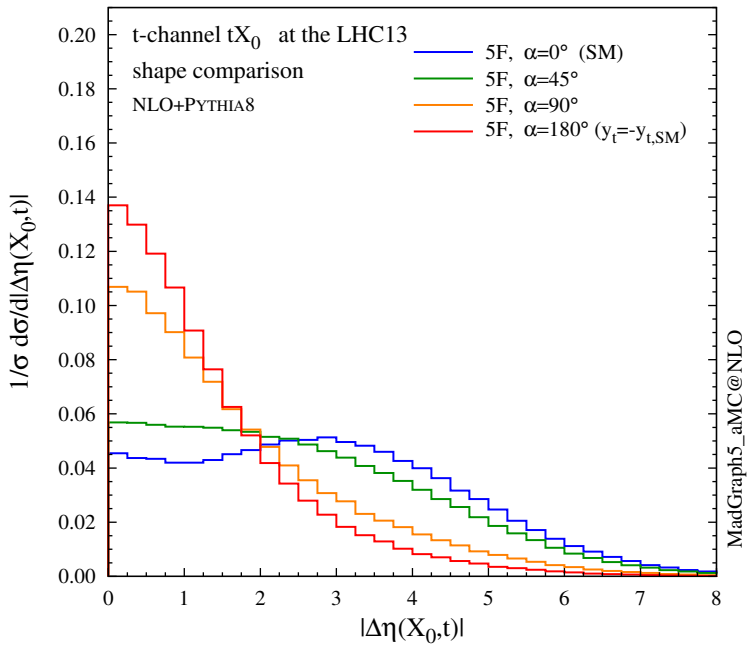
$\alpha \leftrightarrow \pi - \alpha$

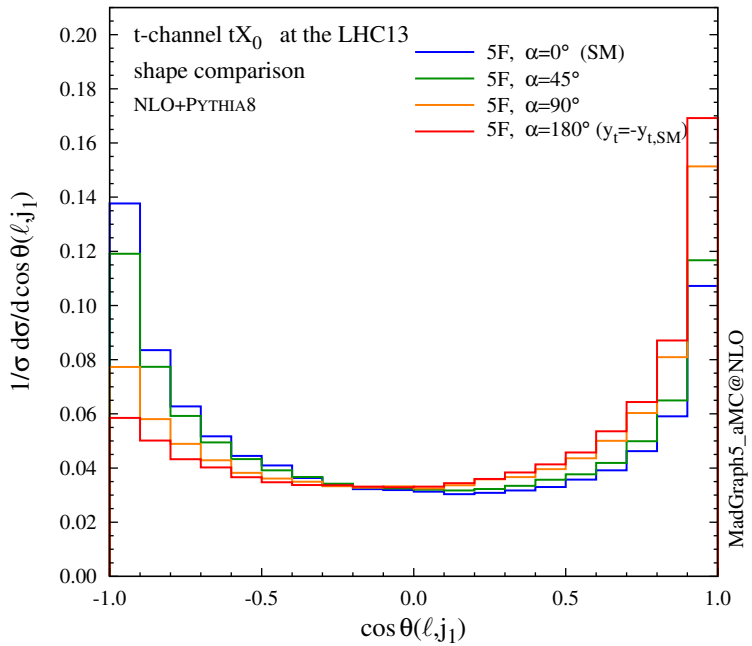
Higgs characterisation: tH distributions



New physics takes place mostly at threshold

Many observables are sensitive to n.p.!





Conclusions (2)

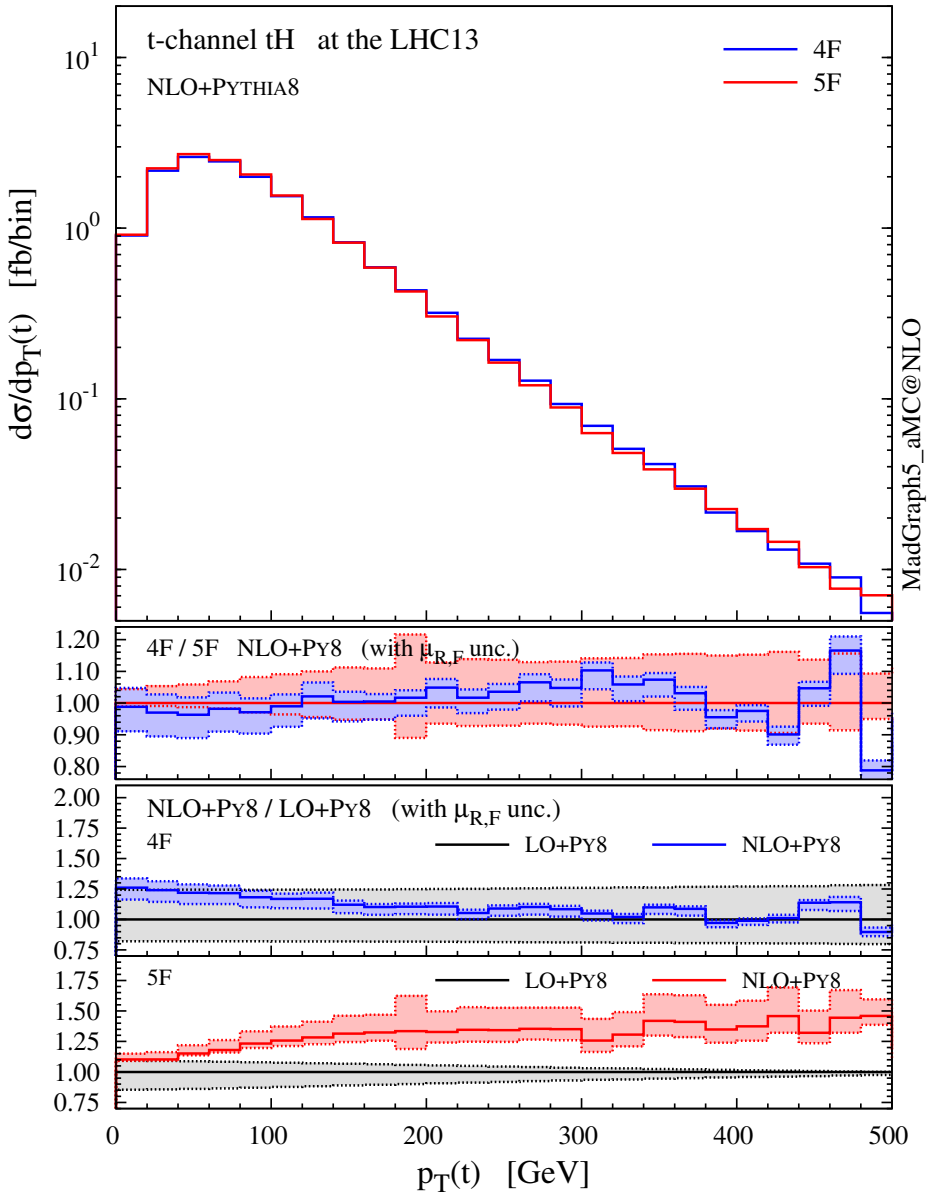
1. Global analysis of different Higgs productions/decays
   improve measurements and lift degeneracies in GF or $t\bar{t}H$

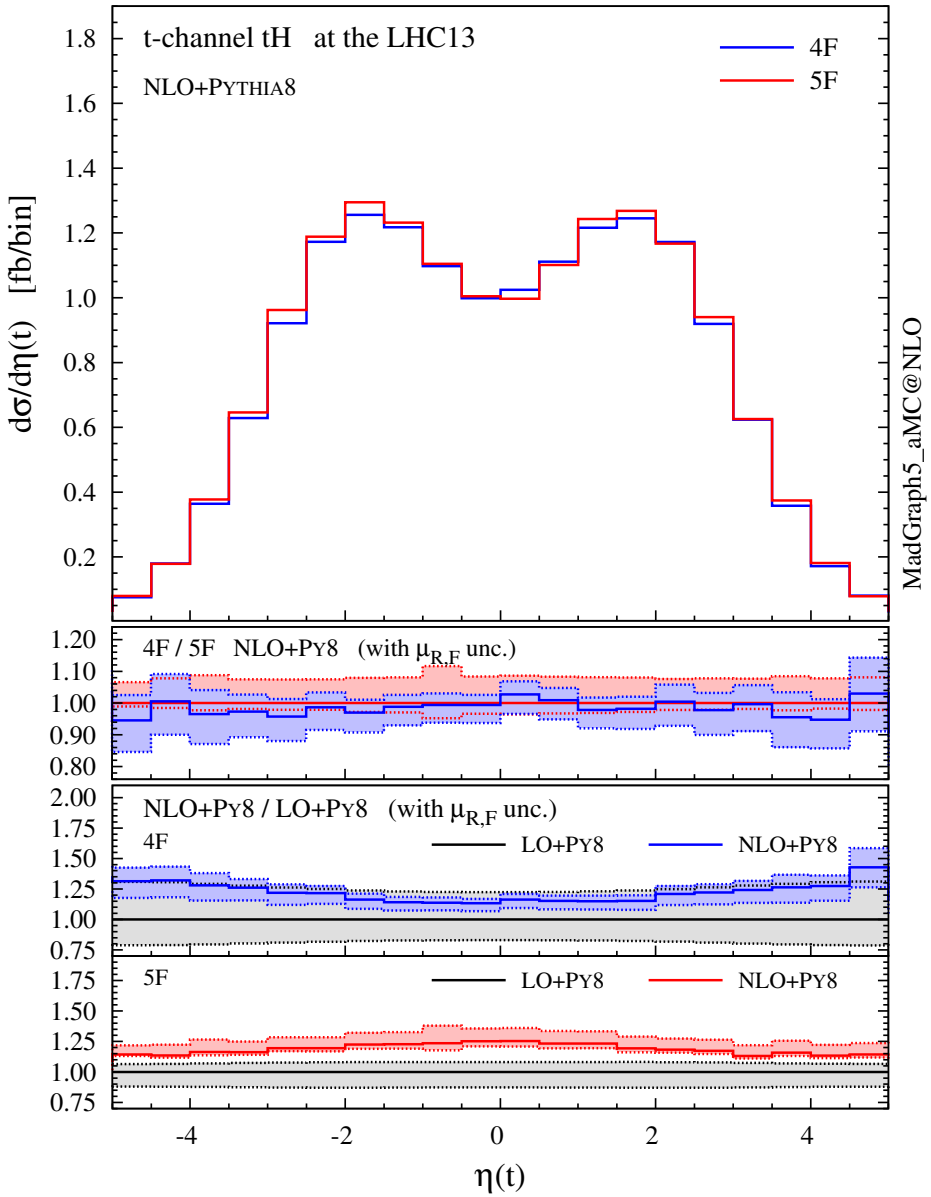
2. Higgs plus single top is a rare process, but provides
   a variety of observables sensitive to BSM physics
   $\Rightarrow$ very interesting for Higgs characterisation

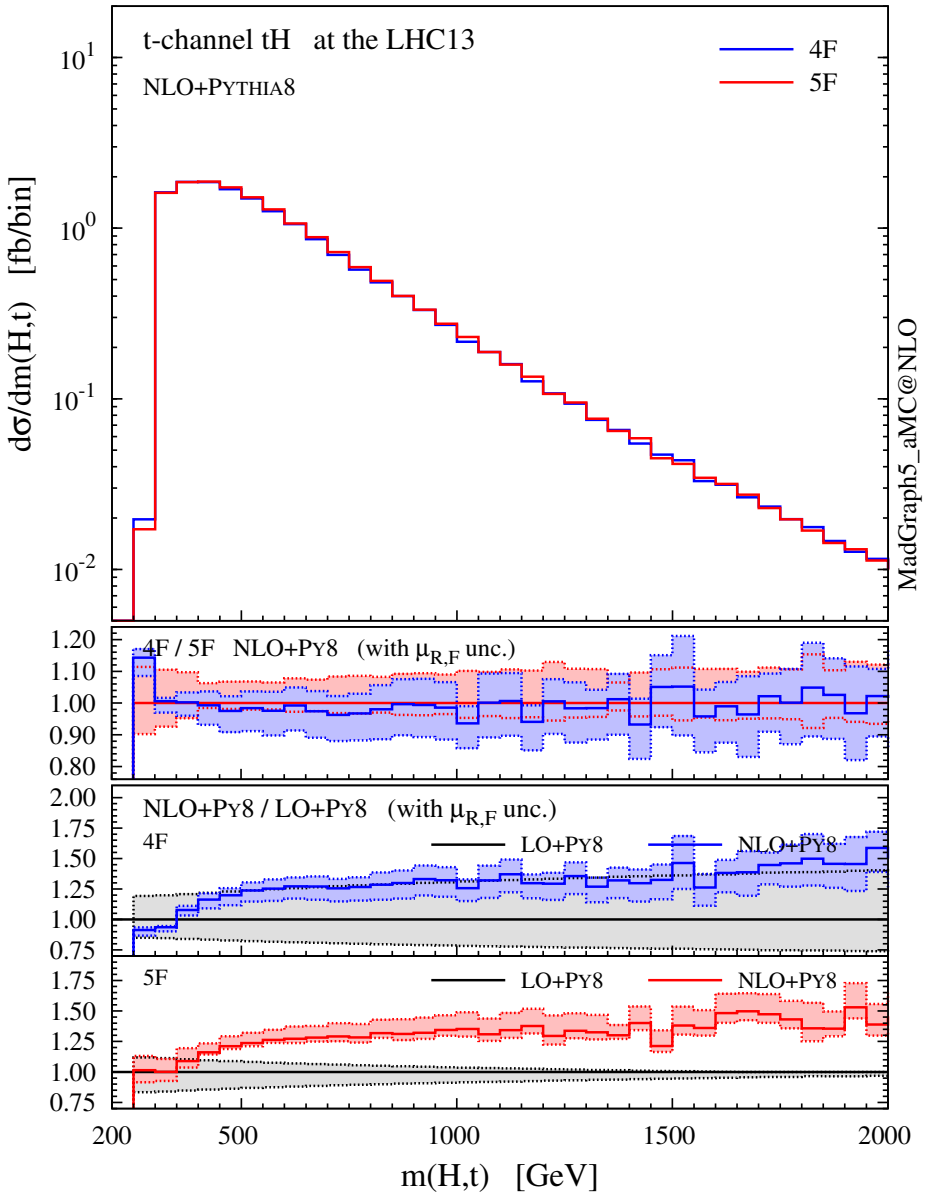
NB: Pheno studies are fully automatic, importing the `HC_NLO_X0` model inside the `MadGraph5_aMC@NLO` framework

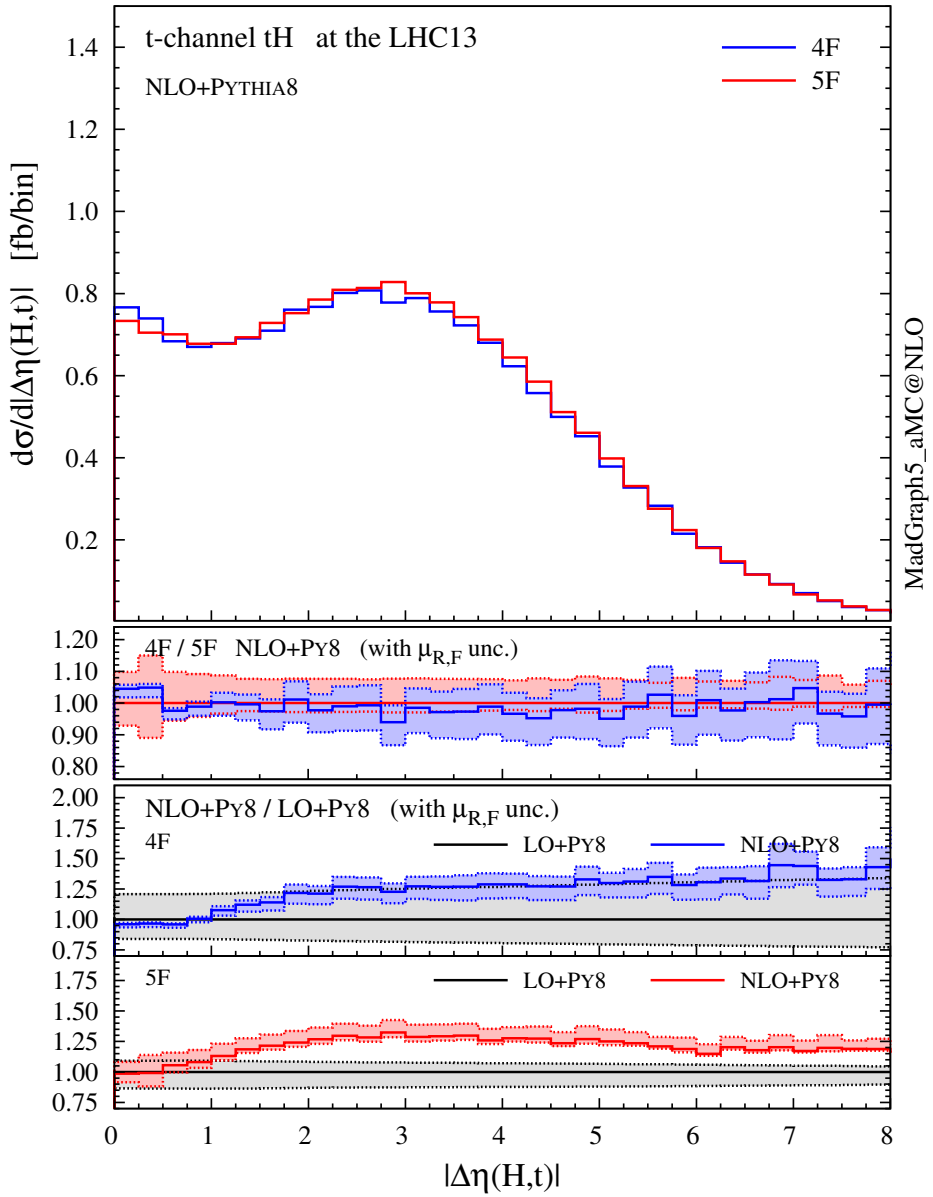
Thanks for your attention!

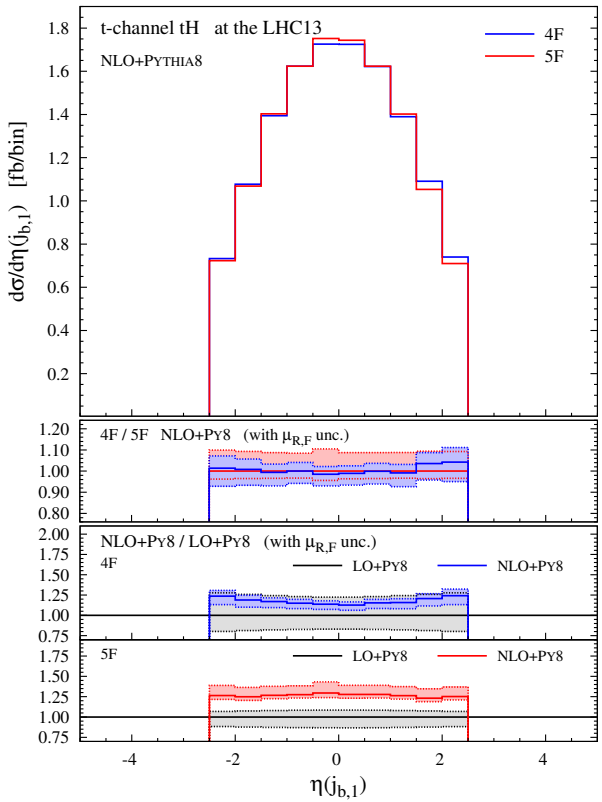
backup slides

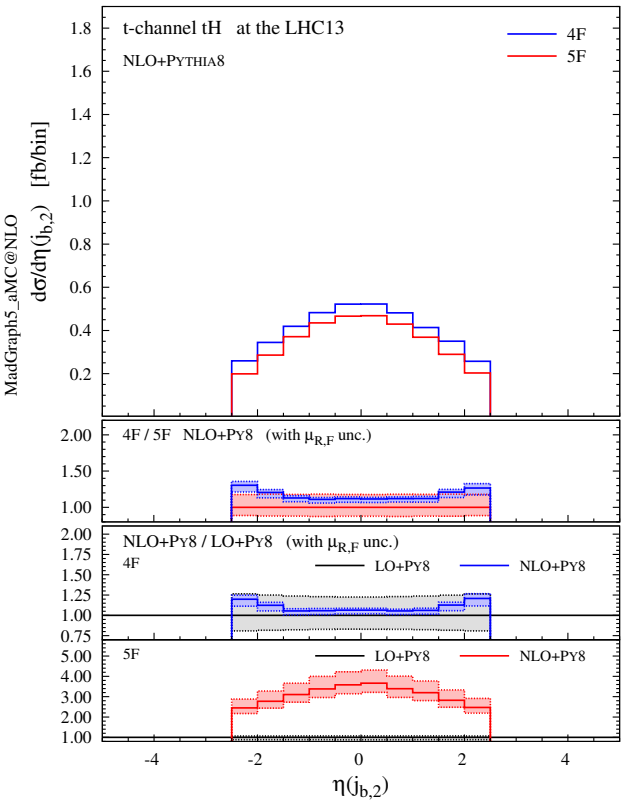

t-channel tH at the LHC13
NLO+PYTHIA8
4F
5F
dσ/dp_T(t) [fb/bin]
MadGraph5_aMC@NLO
4F / 5F NLO+PY8 (with μ_R,F unc.)
NLO+PY8 / LO+PY8 (with μ_R,F unc.)
4F
LO+PY8
NLO+PY8
5F
p_T(t) [GeV]

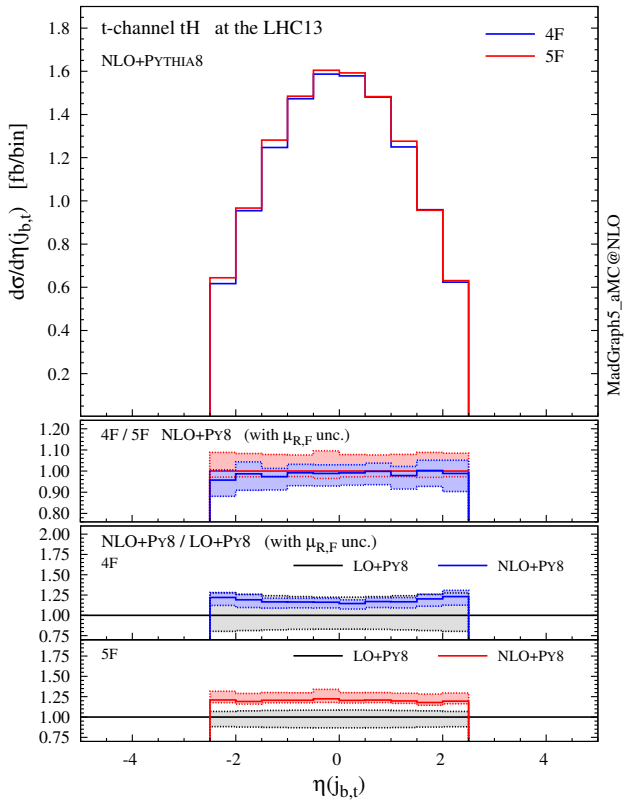

t-channel tH at the LHC13
NLO+PYTHIA8
4F
5F
dσ/dη(t) [fb/bin]
MadGraph5_aMC@NLO
4F / 5F NLO+PY8 (with μ_R,F unc.)
NLO+PY8 / LO+PY8 (with μ_R,F unc.)
4F
LO+PY8
NLO+PY8
5F
η(t)

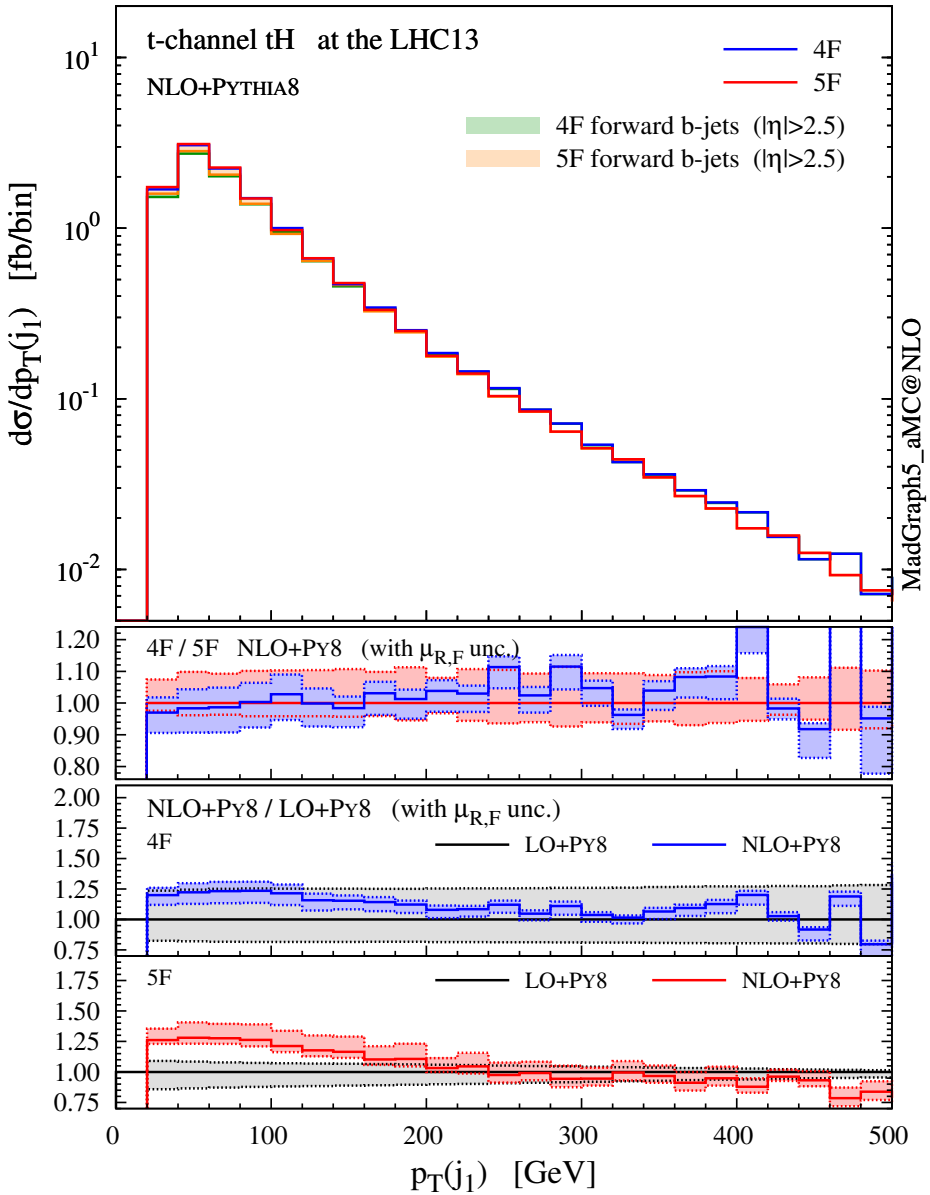

t-channel tH at the LHC13
NLO+PYTHIA8
4F
5F
dσ/dm(H,t) [fb/bin]
MadGraph5_aMC@NLO
4F / 5F NLO+PY8 (with μR,F unc.)
NLO+PY8 / LO+PY8 (with μR,F unc.)
4F
LO+PY8
NLO+PY8
5F
LO+PY8
NLO+PY8
m(H,t) [GeV]

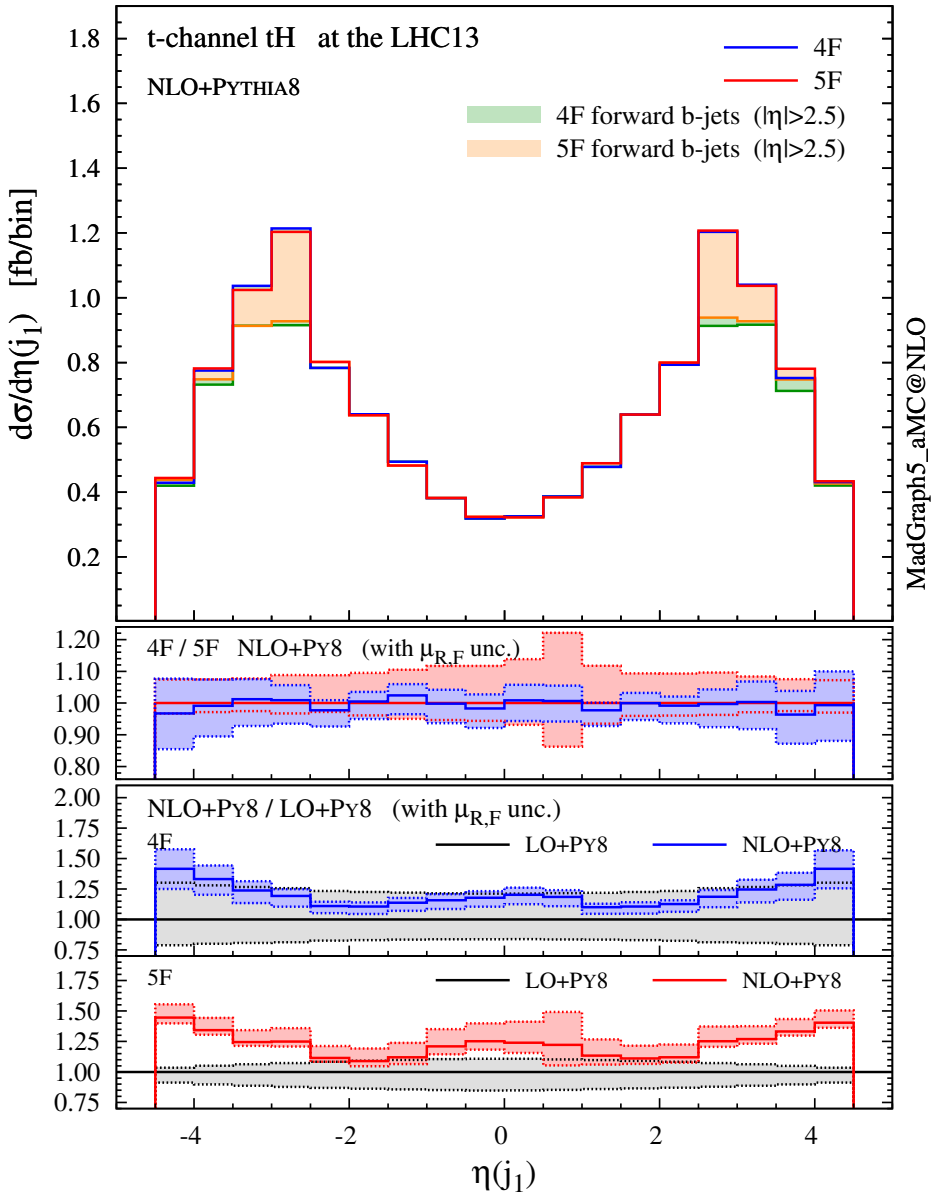

t-channel tH at the LHC13
NLO+PYTHIA8
4F
5F
dσ/d|Δη(H,t)| [fb/bin]
MadGraph5_aMC@NLO
4F / 5F NLO+PY8 (with μR,F unc.)
NLO+PY8 / LO+PY8 (with μR,F unc.)
4F
LO+PY8
NLO+PY8
5F
LO+PY8
NLO+PY8
|Δη(H,t)|

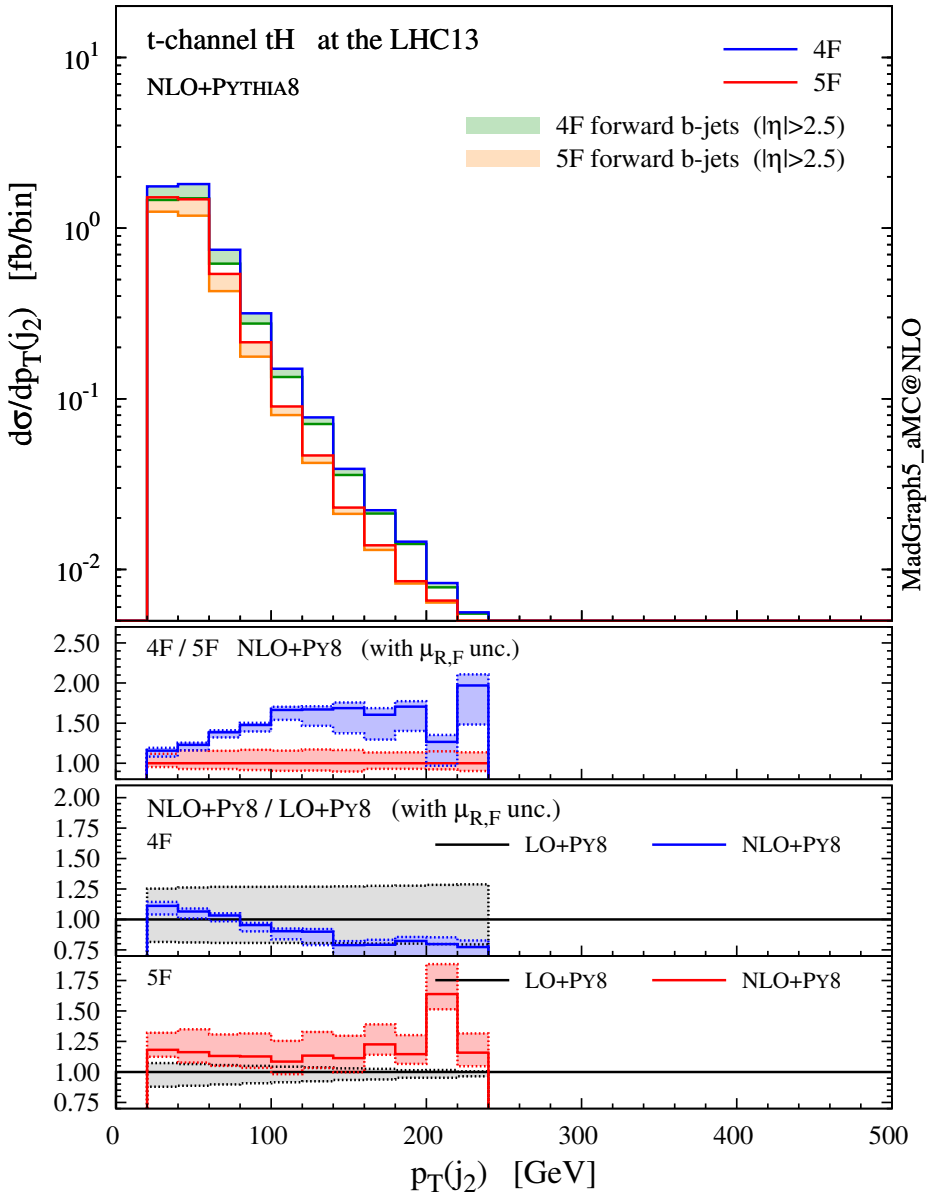

t-channel tH at the LHC13
NLO+PYTHIA8
4F
5F
dσ/dη(j_{b,1}) [fb/bin]
MadGraph5_aMC@NLO
4F / 5F NLO+PY8 (with μ_{R,F} unc.)
NLO+PY8 / LO+PY8 (with μ_{R,F} unc.)
LO+PY8
NLO+PY8
η(j_{b,1})

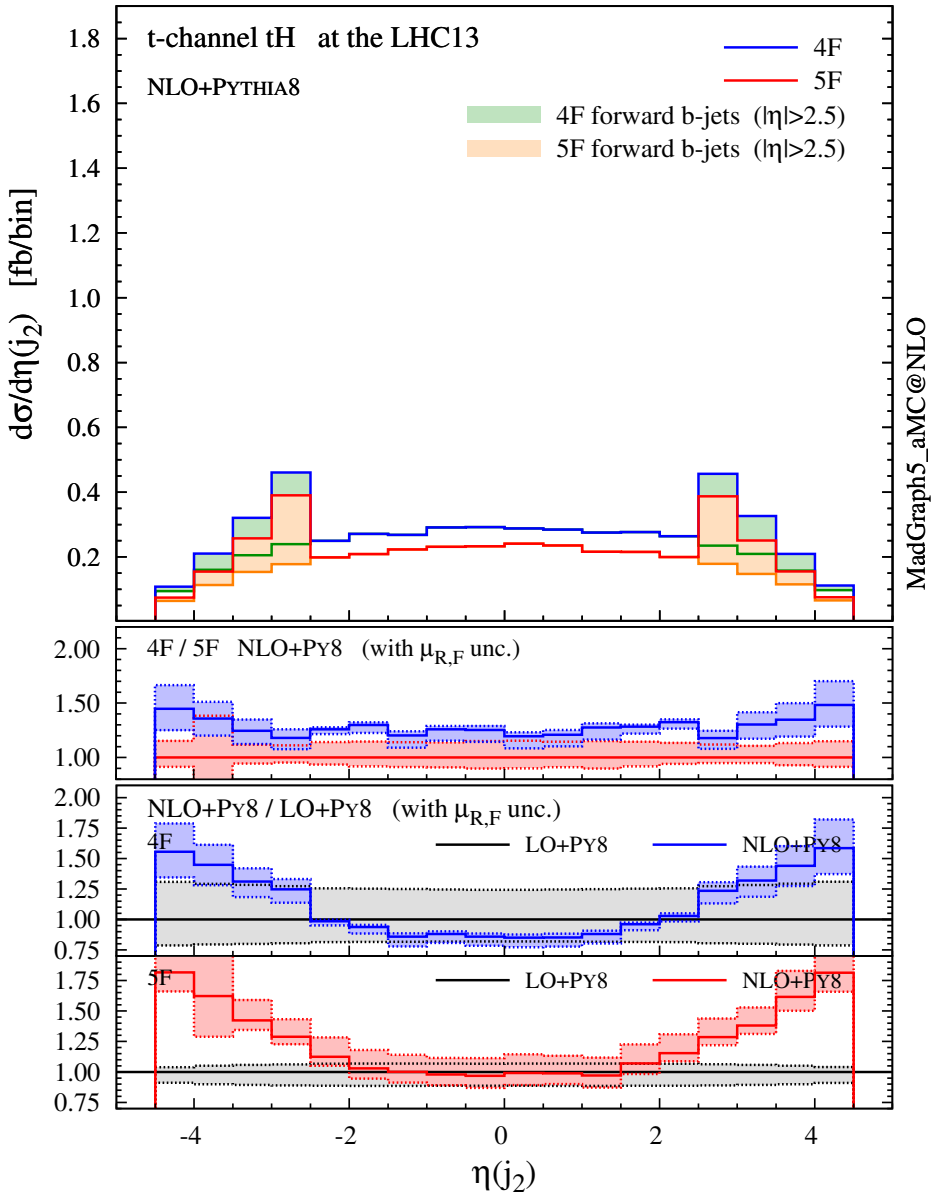

t-channel tH at the LHC13
NLO+PYTHIA8
4F
5F
dσ/dη(j_{b,2}) [fb/bin]
MadGraph5_aMC@NLO
4F / 5F NLO+PY8 (with μ_{R,F} unc.)
NLO+PY8 / LO+PY8 (with μ_{R,F} unc.)
LO+PY8
NLO+PY8
η(j_{b,2})


t-channel tH at the LHC13
NLO+PYTHIA8
4F
5F
dσ/dη(j_{b,t}) [fb/bin]
MadGraph5_aMC@NLO
4F / 5F NLO+PY8 (with μ_{R,F} unc.)
NLO+PY8 / LO+PY8 (with μ_{R,F} unc.)
LO+PY8
NLO+PY8
η(j_{b,t})


t-channel tH at the LHC13
NLO+PYTHIA8
4F
5F
4F forward b-jets (|η|>2.5)
5F forward b-jets (|η|>2.5)
dσ/dp_T(j_1) [fb/bin]
MadGraph5_aMC@NLO
4F / 5F NLO+PY8 (with μ_R,F unc.)
NLO+PY8 / LO+PY8 (with μ_R,F unc.)
LO+PY8
NLO+PY8
p_T(j_1) [GeV]


t-channel tH at the LHC13
NLO+PYTHIA8
4F
5F
4F forward b-jets (|η|>2.5)
5F forward b-jets (|η|>2.5)
dσ/dη(j_1) [fb/bin]
MadGraph5_aMC@NLO
4F / 5F NLO+PY8 (with μ_R,F unc.)
NLO+PY8 / LO+PY8 (with μ_R,F unc.)
LO+PY8
NLO+PY8
η(j_1)


t-channel tH at the LHC13
NLO+PYTHIA8
4F
5F
4F forward b-jets (|η|>2.5)
5F forward b-jets (|η|>2.5)
dσ/dp_T(j_2) [fb/bin]
MadGraph5_aMC@NLO
4F / 5F NLO+PY8 (with μ_R,F unc.)
NLO+PY8 / LO+PY8 (with μ_R,F unc.)
4F
5F
LO+PY8
NLO+PY8
p_T(j_2) [GeV]


t-channel tH at the LHC13
NLO+PYTHIA8
4F
5F
4F forward b-jets (|η|>2.5)
5F forward b-jets (|η|>2.5)
dσ/dη(j_2) [fb/bin]
MadGraph5_aMC@NLO
4F / 5F NLO+PY8 (with μ_R,F unc.)
NLO+PY8 / LO+PY8 (with μ_R,F unc.)
4F
5F
LO+PY8
NLO+PY8
η(j_2)

s-channel ($\simeq$ 3 fb) $<<$ t-channel, but shapes are very different